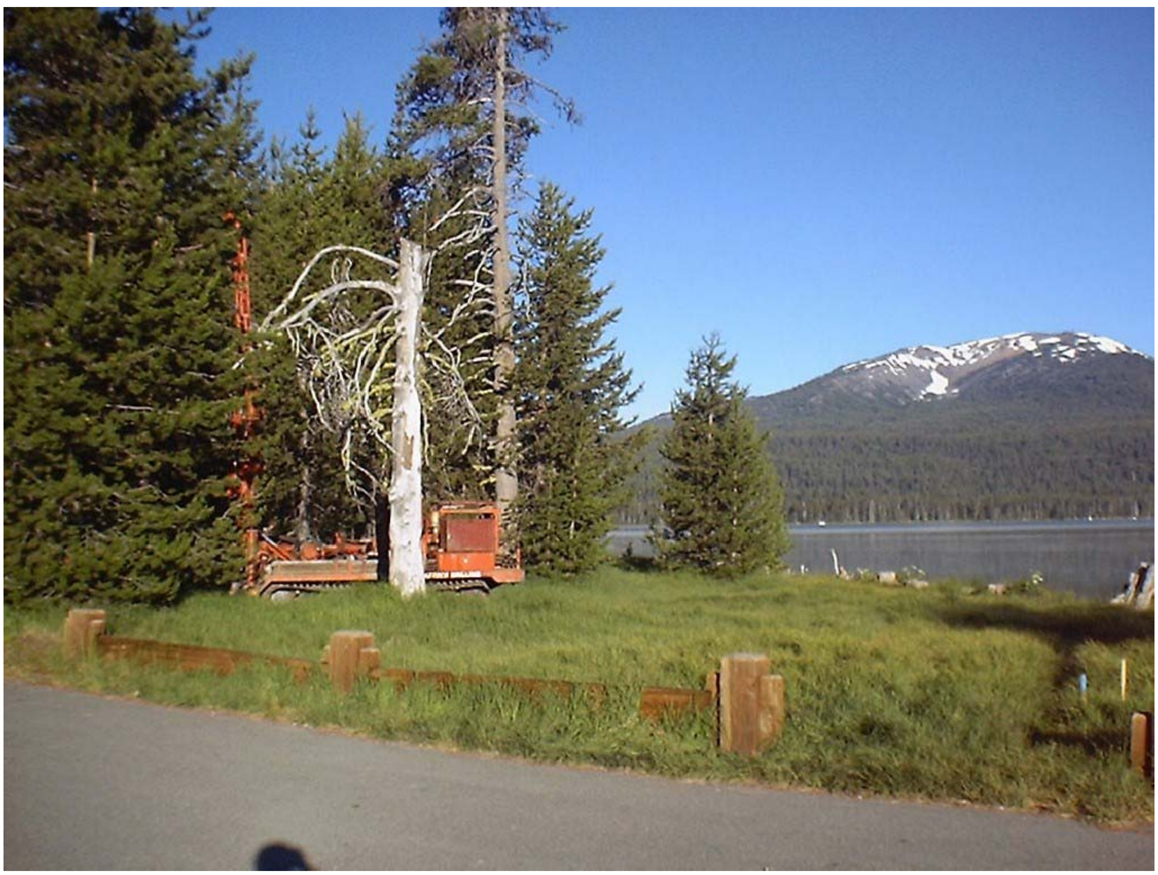
DIAMOND LAKE RESTORATION

Groundwater Report



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November 2004

GROUNDWATER

Groundwater flow patterns in the project area are relevant to three significant issues identified in scoping and described in Chapter 1 of the EIS: water quality, non-target species, and wetlands. Scoping identified a concern that rotenone treated water would escape Diamond Lake through the groundwater and negatively impact water quality and fish and wildlife species in Lake Creek and the North Umpqua River System. This issue is tracked under the title groundwater investigation and is also discussed in the fish and wildlife sections. There is also a concern that water containing rotenone would migrate through the groundwater into the drinking water wells of the summer homes on the west side of Diamond Lake. This issue is tracked under the title water quality-water chemistry. Finally, scoping identified a concern that drawing down Diamond Lake would have a negative impact on wetlands adjacent to the lake. This issue is tracked under the title water quantity-groundwater discharge and recharge, and is also discussed in the terrestrial and wetland plant sections.

BACKGROUND- AFFECTED ENVIRONMENT

Groundwater can be defined as that subsurface water that occurs beneath the water table in soils and other geologic formations that are fully saturated (Freeze and Cherry 1979). Water enters the groundwater system as precipitation or snow melt infiltrating soil and rock through cracks and pores eventually migrating down to the saturated zone[1] where groundwater actually flows. In some instances recharge areas can be an impoundment such as a lake or pond. After entering the ground it moves through the system to discharge areas, which are areas where subsurface water is discharged to streams or other bodies of surface water, such as lakes or ponds. Storage and flow of groundwater are controlled to a large extent by geology. In the Diamond Lake watershed, the geology is a major factor controlling recharge and discharge to both a shallow and a deep aquifer. The pumice soils generated from volcanic activity have high infiltration rates that allow a high percentage of the precipitation and snow pack to recharge the aquifers.

The principle geologic factors that influence groundwater movement are porosity and permeability of the rock or soil material through which it flows. Porosity, in general terms, is the proportion of a rock or deposit that consists of open space. In a gravel deposit, this would be the space between the individual pebbles and cobbles. Permeability is a measure of the resistance to the movement of water through the

[1] Saturated zone is the depth, below which all of the pores in the soil or geologic matrix are filled with water, thus allowing the water to flow.

rock or deposit. Deposits with large interconnected spaces, such as gravel, have little resistance to groundwater flow and are therefore considered highly permeable. Rock or deposits with few, very small, or poorly connected open spaces offer considerable resistance to groundwater flow and, therefore, have low permeability.

The hydraulic characteristics of geologic materials vary between rock types and within particular rock or soil types. For example, in sedimentary deposits the permeability is a function of grain size and the range of grain sizes (degree of sorting). Coarse, well-sorted gravel has much higher permeability than fine, silty sand deposits. The permeability of lava flows can also vary markedly depending on the degree of fracturing. The highly fractured, rubbly zones at the tops and bottoms of lava flows and in the interflow zones are often highly permeable, while the dense interior parts of lava flows can have very low permeability (Gannet, 2001).

Sherrod (1986, 1991) describes the surficial geologic material of the Diamond Lake basin as consisting of glacial drift (Qgd), lacustrine (Ql), and ash (Qaf) deposits resting on top of the basaltic andesite bedrock, see Figure 1. These surficial deposits comprise a shallow unconfined aquifer in the Diamond Lake basin. The glacial deposits consist of stratified and unstratified drift with particle size ranging from silt to boulders. The lacustrine deposits are comprised of well-bedded[2] unconsolidated sand and gravel consisting primarily of medium to coarse grained crystal-lithic-pumice sand that is generally medium to well sorted, thin to medium bedded, and parallel bedded. Some lacustrine deposits are as high as eight meters above the current lake level. The ash deposits are from the Mount Mazama eruption and consist mainly of unsorted, pale-grayish-white ash. At Diamond Lake the ash flows ponded in excess of 12 m, as interpreted from water-well cuttings (Sherrod 1991).

[2] Bedded refers to the distinct layering of sediment that accumulates over time in the lake basin and can usually be detected visually.

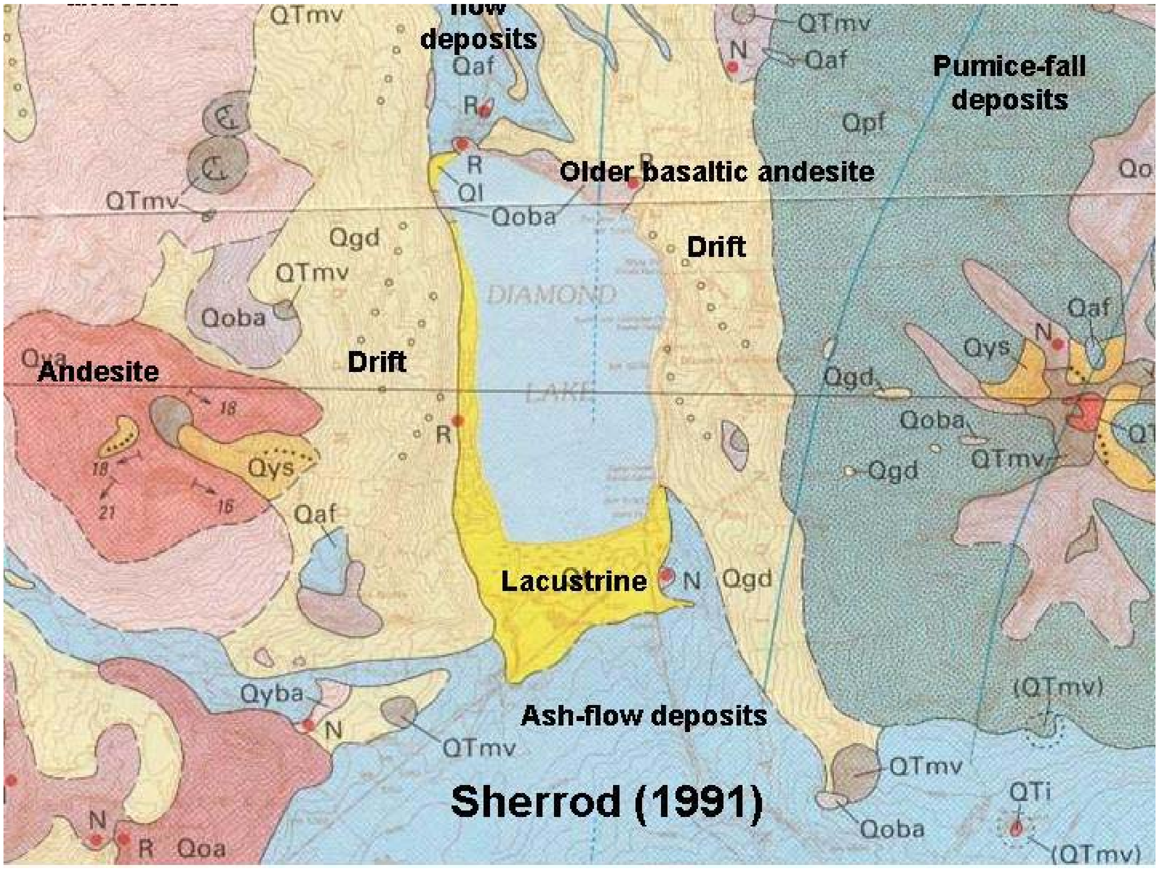


Figure 1. Geologic map of Diamond Lake, showing the Drift, Lacustrine, and Ash flow deposits.

The Regional groundwater flow direction in the Diamond Lake watershed follows the typical pattern of a mountainous terrain. Groundwater is recharged via snow melt and rain infiltrating into the soil and bedrock which percolates down, following the pattern of topographic relief until it reaches the lake, where it discharges. In the Diamond Lake area, groundwater recharge occurs mainly at the higher elevation in the mountains above and around the lake. Also, recharge occurs to both, a deep basaltic bedrock aquifer, which is typically greater than 100 feet below the ground surface as well as to the shallow aquifer. The shallow groundwater aquifer generally follows the perimeter of the lake until it pinches out along the eastern, western and northern shores. Along the southern boundary of the lake, the shallow aquifer extends south to encompass the lacustrine deposits and some of the ash deposits, shown on Figure 1. The exact extent of the shallow aquifer south of the lake has not been investigated and therefore is not known at this time.

GROUNDWATER INVESTIGATION

Monitoring Wells

Any impacts to the groundwater from contaminated lake water are expected to occur in the shallow aquifer not the deep aquifer. In the Diamond Lake basin, the deep aquifer is confined and exhibits artesian conditions. What this means is that water in the deep aquifer is separated from the shallow aquifer by an impermeable layer of rock and the water in the deep aquifer is confined and under pressure. When a well is installed into the deep aquifer, through the impermeable rock layer, the water level in the well will rise (see Figure 2). If the water level rises above the ground surface, it is referred to as a flowing artesian well. In the Diamond Lake area this artesian flow is evidenced by the springs that form Silent Creek and Short Creek and the water level in the wells of some summer cabins that have deep wells which penetrate into the deep aquifer. The tendency of water to rise out of the deep aquifer will act to inhibit shallow groundwater from infiltrating into the deep aquifer, acting as a barrier restricting the downward migration of water from the shallow aquifer. Therefore, if the shallow aquifer were to become contaminated with rotenone or algal toxins they are not expected to migrate into the deep aquifer.

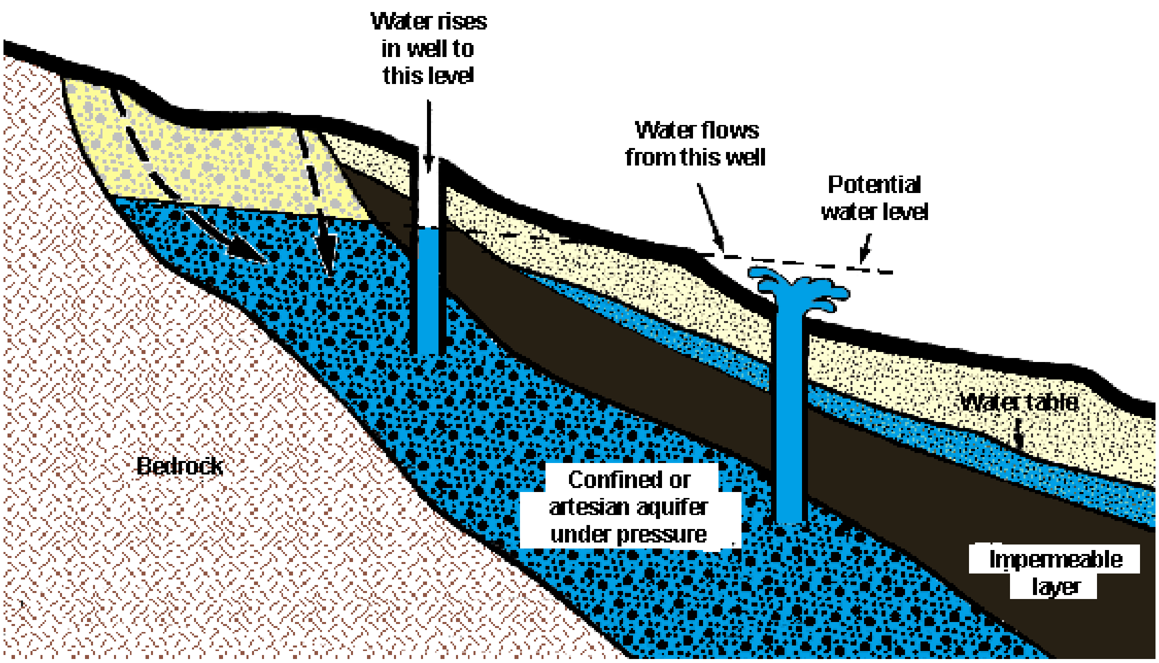


Figure 2. Shallow and Deep Aquifers. In the Diamond Lake area, the deep aquifer is confined by a layer of impermeable material which causes the groundwater to be under pressure. The shallow aquifer is unconfined and not under pressure.

Though it is not likely that the deep aquifer could become contaminated by toxins from the lake, the shallow aquifer might. Therefore, a groundwater investigation was initiated during the summer of 2003 to determine the characteristics of the shallow aquifer surrounding Diamond Lake. The shallow aquifer is the source of many shallow wells used by summer home residents and one campground. A total of sixteen monitoring wells, installed as pairs, 300 to 600 feet apart, were placed at various locations around the lake (Figure 3).

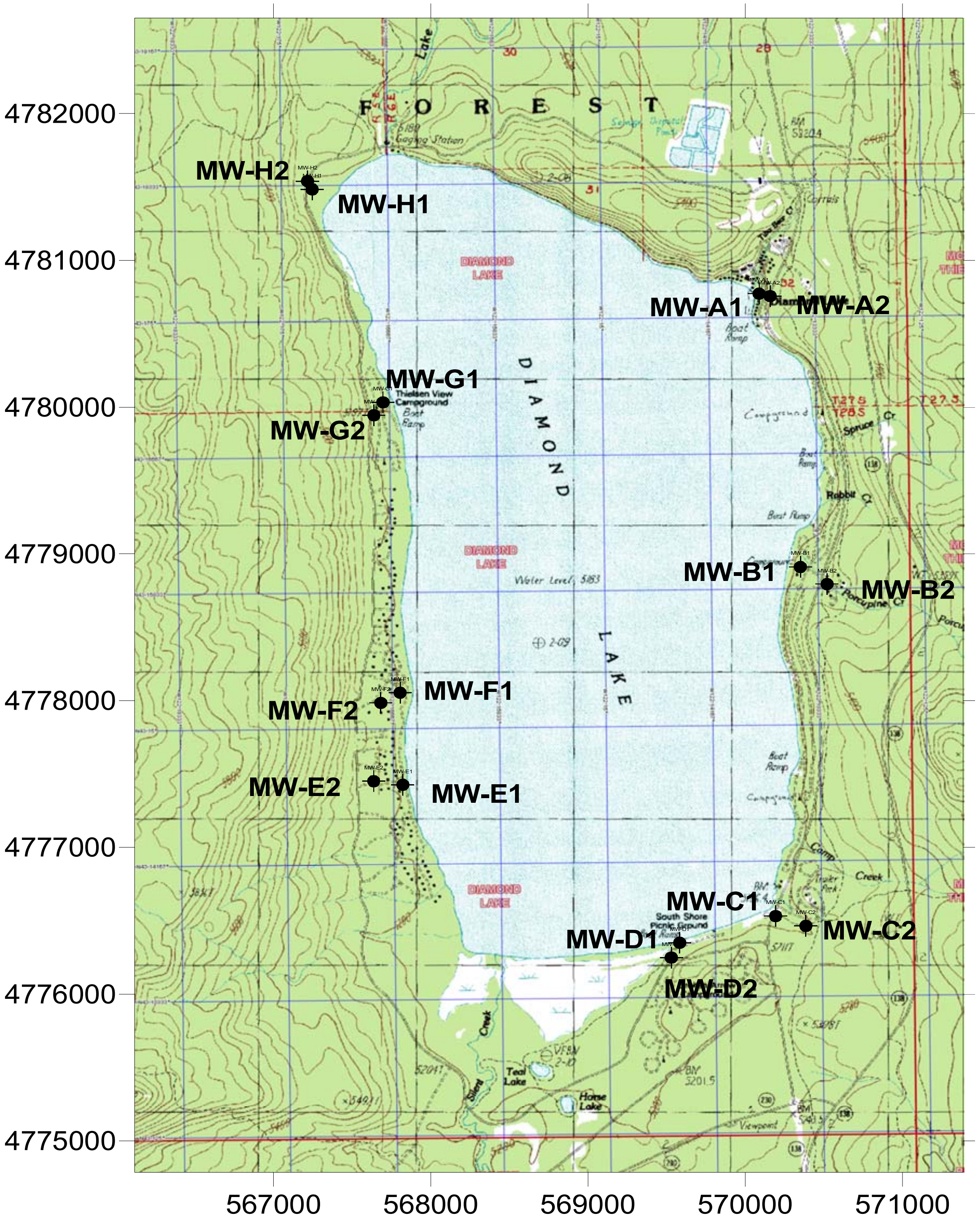


Figure 3. Groundwater Monitoring Well Locations in the Shallow Unconfined Aquifer at Diamond Lake

Groundwater monitoring wells were installed and screened at depths approximately 10 to 15 feet below the level of lake draw down proposed in Alternatives 2, 3, and 5. See the Groundwater report for the depth and screened interval for each well. Having the wells screened at these depths allows for determining changes that may occur in the direction of groundwater flow before, during, and after any manipulations of the lake level.

Installation and development of the wells was completed on July 29, 2003. Groundwater elevation measurements were collected from August 5, through November 5, 2003 and are included in the discussion of the shallow aquifer. See the Appendix for the groundwater elevation data for all of the wells. Additional groundwater elevation measurements will be collected throughout the winter and spring of 2003 -2004. The data will indicate any change to the groundwater flow direction over the period when elevation measurements are collected. Changes in the groundwater flow pattern are expected to occur as the groundwater elevation rises and drops throughout the normal yearly hydrologic cycle. As recharge diminishes over the summer and groundwater elevations drop to below the level of the lake, the direction of groundwater flow can reverse. When this occurs, the lake begins to recharge the groundwater and will continue to do so until the level of groundwater rises above that of the lake, or the lake level is lowered to below that of the groundwater. During the snowmelt in late spring and early summer it is expected that groundwater elevations will rise and all groundwater will discharge into the lake. Figure 4 shows the various flow patterns that can occur around a lake such as Diamond Lake.

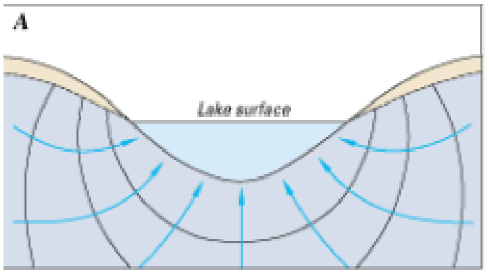


Diagram A illustrates typical groundwater flow patterns in late spring and early summer. Snowmelt and precipitation raise the water table and groundwater moves into the lake.

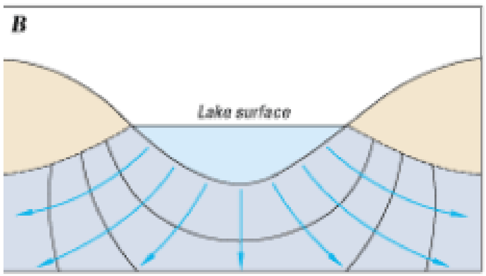


Diagram B illustrates typical groundwater flow patterns in late summer and fall. Water leaves the lake and enters the groundwater aquifer.

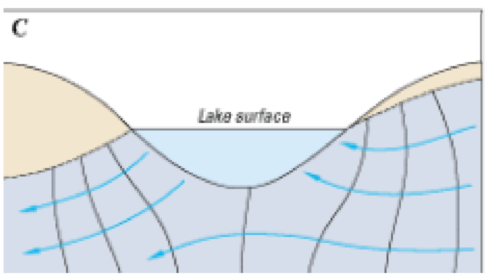


Diagram C illustrates the scenario where groundwater is discharging to the lake, the lake is recharging groundwater, and a portion of groundwater is not interacting with the lake, but flowing beneath it.

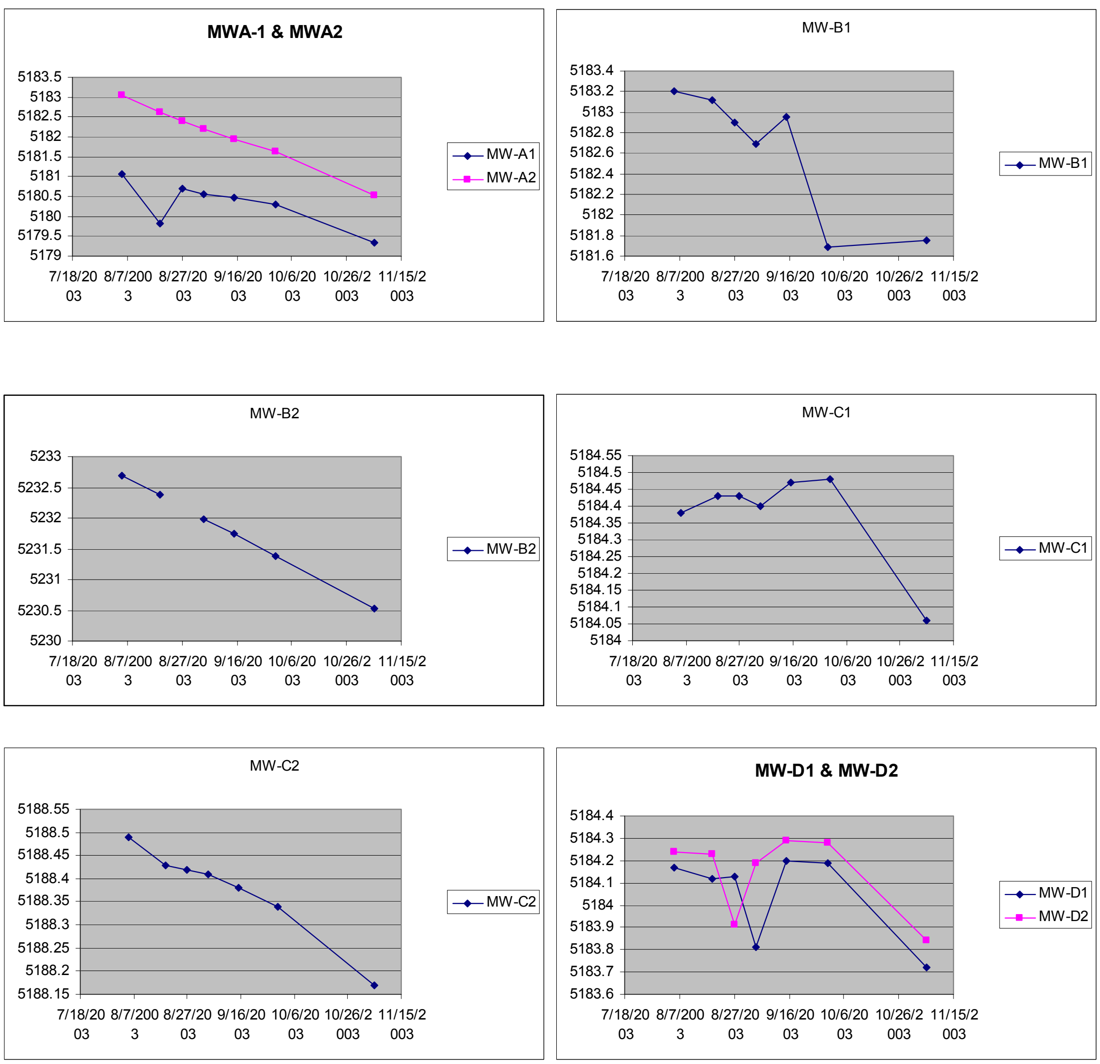
Figure 4. Changes in groundwater flow patterns around a lake. A – groundwater recharge to the lake, B-the lake recharges groundwater, C – the lake acts as both recharge and discharge area (U.S.G.S. Circular 1139)

The current groundwater elevation data indicate that during late spring, summer, and early fall, groundwater flow direction is toward the lake. In an area along the east and northeast near wells MW-A1, MW-A2 and MW-B1, (Figure 3) groundwater levels have been at, or slightly lower than that of the lake from the beginning of the data collection period. However, the hydraulic gradient[3] from the outermost wells has been toward the wells located closest to the lake. In other words, throughout the spring, summer, and early fall the groundwater flow direction is toward the lake as determined from the water elevations in all of the outermost wells. There are no drinking water wells in the shallow aquifer in the area of monitoring wells MW-A1, MW-A2, and MW-B1. Therefore, there is no risk of exposure to rotenone or algal toxins from groundwater in this area.

The groundwater flow direction is expected to reverse as the water table continues to drop throughout the year. Once flow reversal has occurred, lake water will recharge the shallow aquifer and will continue until spring snow melt. The predicted time when

[3] Hydraulic gradient is the difference in water level between two wells divided by the distance between them and has units of ft/ft. The direction of groundwater flow is from the well with the higher level to that with the lower level.

flow reversal will occur (for those wells not already exhibiting reversal) was calculated from the hydrographs for those wells. The hydrographs for each monitoring well are shown in Figure 5. Flow reversal is predicted to occur in all monitoring wells except MW-B2 by February 2004.   Table 1 shows the rate of drop in groundwater levels and Table 2. shows the actual or predicted time when the groundwater level will drop below that of the lake. MW-B2 is not expected to fall below the level of the lake. Wells MW-E1, MW-E2, MW-F1 and MW-F2 are all located on the western shore in the area of the summer homes, and as such are the wells which are monitored to determine when flow reversal occurs and if contaminated lake water is flowing toward the summer home wells. Table 2 shows that flow reversal occurred at wells MW-E1 and MW-F1 (closest to the lake) by mid August, but that the outer set of wells still showed a gradient toward the lake. However, the predicted time for reversal to occur in the outer wells is mid November. The data indicates that water from the lake will begin recharging the groundwater in the summer home area by mid August and is expected to continue until the groundwater table rises during spring snowmelt.   That is the time period when the summer home wells could potentially become impacted from contaminated lake water.



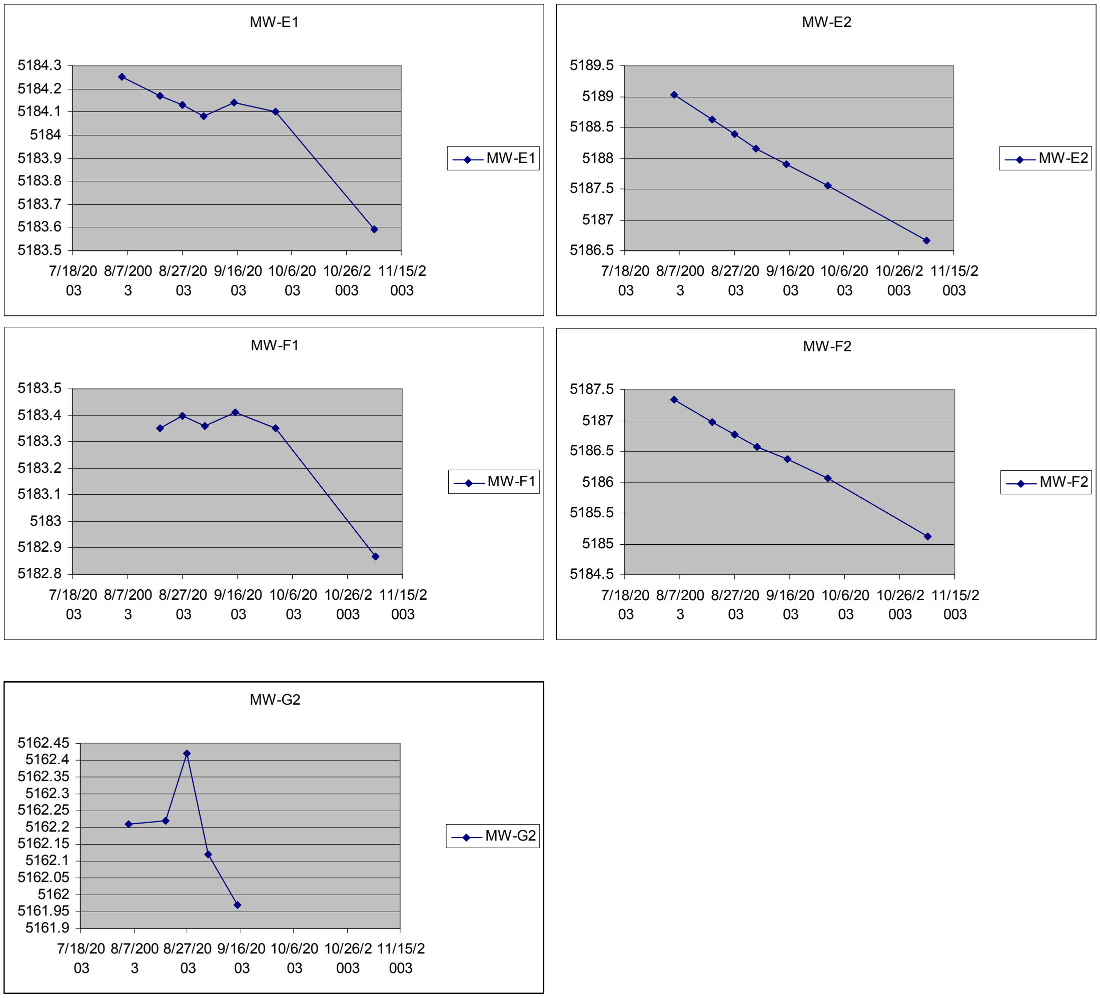


Figure 5. Hydrographs for Diamond Lake Wells

Table 1. Rate of Drop in Groundwater levels

Rate of Drop of Ground Water in the Wells from August 5, 2003 Through November 5, 2003				
WELL NUM	Total Change-Ft	Rate of Change Inches/Week		
MW-A1	-1.73	-1.6		
MW-A2	-2.54	-2.3		
MW-B1	-1.45	-1.3		
MW-B2	-2.17	-2.0		
MW-C1	-0.32	-0.3		
MW-C2	-0.32	-0.3		
MW-D1	-0.45	-0.42		
MW-D2	-0.40	-0.37		
MW-E1	-0.66	-0.61		
MW-E2	-2.36	-2.18		
MW-F1	-3.31	-3.1		

MW-F2	-2.22	-2.0		
MW-G2	-0.24	-0.26		

Table 2. Actual or predicted groundwater flow reversal for Diamond Lake monitoring wells.

Well Number	Inches above lake as of November 5,2003	Actual or Predicted Time of Reversal
MW-A1	-4.46	08/05/2003
MW-A2	-3.28	08/05/2003
MW-B1	-2.05	08/05/2003
MW-B2	46.73	Not expected to occur
MW-C1	0.26	11/12/2003
MW-C2	4.37	02/18/2004
MW-D1	-0.08	11/05/2003
MW-D2	0.04	11/12/2003
MW-E1	-0.21	08/19/2003
MW-E2	2.87	11/18/2003
MW-F1	-0.93	08/19/2003
MW-F2	1.31	11/12/2003
MW-G1	Dry Well	N/A
MW-G2*	-21.8	08/05/03
MW-H1	Dry Well	N/A
MW-H2	Dry Well	N/A

* The very small amount of water (2 inches) temporarily in MW-G2 may have been from water introduced into the borehole to hydrate the bentonite seal.

Wells installed in Thielson campground (MW-G1) and in the far northwest corner (MW-H1 and MW-H2) have been dry since data collection began. MW-G2 had two inches of water in the well after completion, but soon became dry. The water in the well may have been from water used to hydrate the bentonite seal and not groundwater. These wells were drilled to a depth of 19 to 24 feet below the current level of the lake and, as with the other wells, were expected to intercept groundwater at those depths. However, since these wells are dry, two things could be occurring: either there is no groundwater in this area, or a steep gradient exists and groundwater is exiting the lake at a depth greater than the screened interval of the wells. In order to answer this question, the U.S. Forest Service will conduct additional hydrogeologic investigation in this area in spring 2004.

Downstream Seepage Study

If groundwater is migrating out of the lake basin at a depth below which the current wells can monitor, it could be discharging into Lake Creek. Therefore, it was necessary to determine if it was surfacing in Lake Creek, downstream of the outlet. In September 2003, the U.S. Forest Service conducted a groundwater seepage study along a six mile length of the Lake Creek. The study was conducted while the creek was at base flow. A series of stream gauging transects were completed at intervals along Lake Creek (Figure 6). Any increase in flow to Lake Creek at base flow, not including that from tributaries, could only come from groundwater discharge, which [4] could possibly be coming from the northwest area of the lake. The results of this investigation indicate that Lake Creek receives no appreciable increase in flow due to groundwater discharge to the creek. It exhibited a mean flow of 11.48 cfs with a standard deviation of 0.789 cfs. Flow at the first transect (0.25 miles from the outlet of the lake, and representative of surface flow from the outlet) was 11.01 cfs, and six miles downstream at the last transect, was 11.30 cfs, with no greater than 1.52 cfs change in inflow or outflow between transects. See the Appendix for the complete results of the study. The conclusion drawn from this study was that even if groundwater was migrating from the lake basin in the area of MW-H1 and MW-H2 wells, it is not discharging into Lake Creek within the first six miles of the lake outlet, and therefore, chemical treatment would have no deleterious effects on this reach of Lake Creek.

There is the possibility that groundwater could discharge at a location further downstream. However, given the hydraulic conductivity[5] of the shallow aquifer, the time required for a release to travel that distance, and the propensity for migration of rotenone to be severely retarded due to its strong tendency to attach to sediments, it is very unlikely that rotenone would discharge via the groundwater at a concentration that would negatively affect any receiving body of water.

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[4] ODEQ and USFS geologist attempted to extend the wells in the summer of 2004, however equipment failure prevented completion of the well extensions. ODEQ will drill additional monitoring wells in this area in the spring of 2005. Because of the knowledge gained from the seepage study and other groundwater investigations, this information was not considered critical to assessing risks associated with the project, but is still valuable information for acquiring.

[5] Hydraulic conductivity is a measure of the ability of fluid to move through a porous media and is a function of the fluid properties and physical properties of the media such as the size and shape of pores, and effectiveness of the interconnection between the pores. It has units of L/T, (i.e. cm/sec).

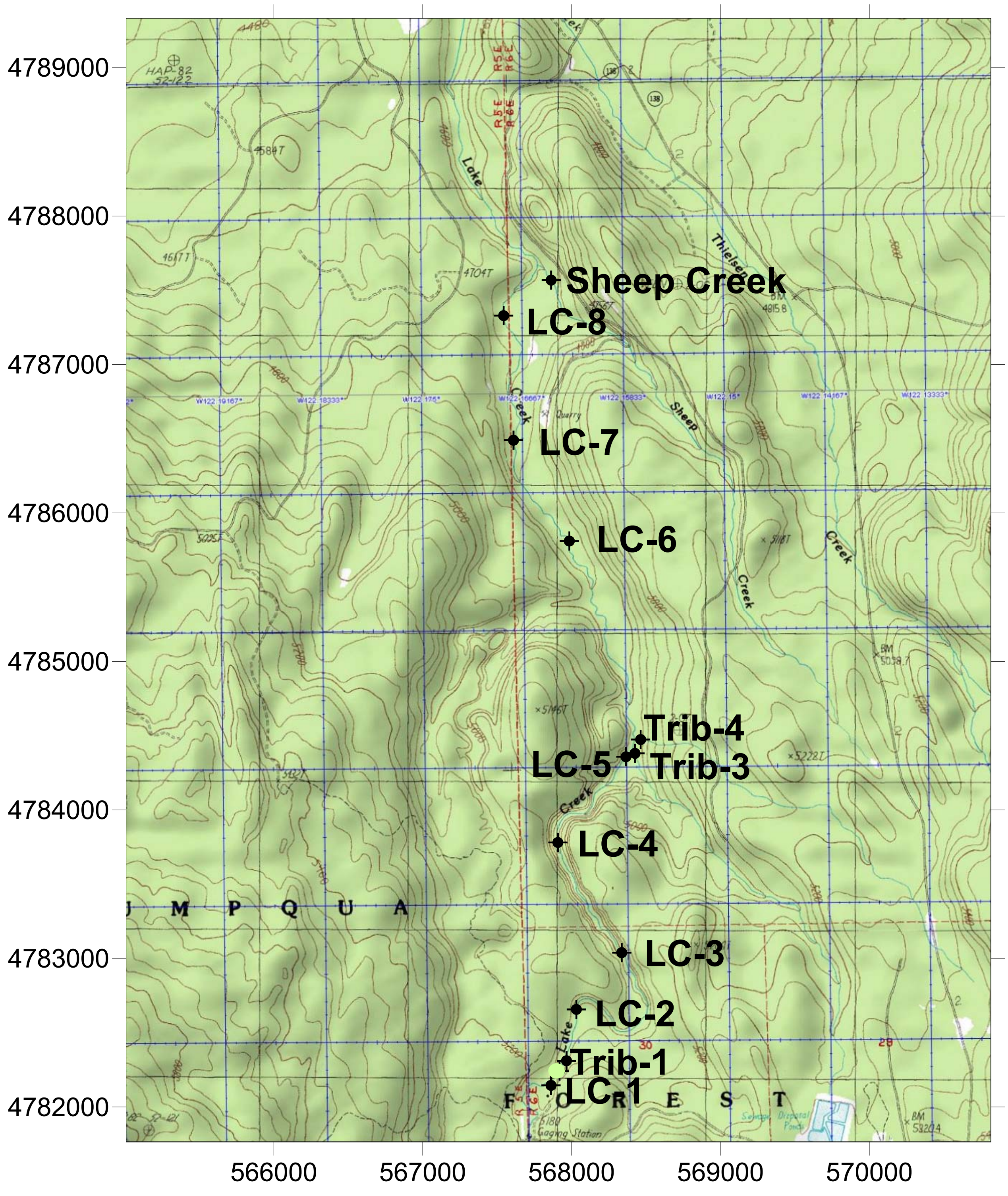

Figure 6. Locations of the Stream Gauging Transects on Lake Creek.

Groundwater Quantity Study

The quantity of ground water flowing into the lake varies as the gradient changes and with the variation of hydraulic conductivity permeability of the geologic material. Pumping tests were conducted on six wells to determine the hydraulic conductivity of the aquifer material. The shallow ground water aquifer at Diamond Lake exhibits a range of hydraulic conductivities of 7.9×10^{-5} cm/sec in the northwestern area of the lake (MW-F2) to 5.92×10^{-2} cm/sec in the southeastern area (MW-C2 and MW-D2). See the Appendix for the results of the pumping tests and the logs for all of the wells.

The quantity of ground water flowing into the lake was estimated by dividing the lake into different sections and calculating the flow for each section. The differentiation for each section was based upon the hydraulic conductivity of the aquifer material associated with a specific well and extending that area from that well to a point midway between the next set of wells. See the Appendix for the map of the sections.

Flow into the lake was calculated in two ways. The first used the well specific values for hydraulic conductivity, hydraulic gradient and the cross sectional areas for a specific well section. This method calculates the flow for each of the defined sections described above. Using this method the combined flow into the lake is approximately 6.5 cfs. The second method used the averaged values for hydraulic conductivity and hydraulic gradient, and set the cross sectional area to 2,112,000 ft^2 (this is the equivalent of 8 miles of shoreline with a discharge depth of 50 feet). The ground water component of flow using the average values is approximately 9 cfs. These values are based on the hydrogeologic conditions that existed at the time the study was conducted and may be either lower or higher depending on climatic conditions and weather patterns that affect the overall snowfall and precipitation, and thus recharge to the aquifer in a given year. The conclusion drawn from this analysis is that the contribution of ground water to the total inflow into the lake is significant and any impacts to ground water from proposed restoration activities could have an impact on the overall ground water quality of the shallow aquifer.

WATER QUALITY – WATER CHEMISTRY

Mixing of groundwater with surface water can have major effects on aquatic environments if factors such as pH, temperature, dissolved oxygen, and nutrients are altered, or the addition of contaminants occurs. Thus, changes in the natural interaction of groundwater and surface water caused by human activities can potentially have a significant effect on aquatic environments. The flow between groundwater and surface water creates a dynamic habitat for aquatic flora and fauna near the interface (hyporheic zone). In most cases, these organisms are part of the food chain that sustains a diverse ecological community. Studies indicate that these organisms may provide important indications of water quality plus adverse changes in aquatic environments. For example, wetlands are dependent on a relatively stable influx of groundwater throughout changing seasonal and annual weather patterns. Therefore, wetlands can be highly sensitive to any change that may impact the groundwater system, such as the lake draw down.

Additionally, it is generally assumed that groundwater is safe for consumption without treatment. The summer cabins along the western shore of the lake depend on groundwater for their source of domestic and potable water supply and have no system to treat or remove contamination if it were to migrate to their wells. Because Alternatives 2, 3, and 5 propose a rotenone treatment in Diamond Lake, it is important to be able to monitor and verify that no chemically treated lake water that enters the groundwater would migrate toward the drinking water wells, nor discharge to Lake Creek. Because Alternative 1 maintains the existing condition, it is also important to know if algal toxins from the lake could be contaminating summer home wells.

AFFECTED ENVIRONMENT

In August 2003, the U.S. Forest Service measured the quality of the groundwater in the shallow aquifer surrounding Diamond Lake. The twelve parameters measured included nutrients, pH, dissolved oxygen, specific ions, conductance, and temperature. The results of this analysis indicate that groundwater quality is excellent, with none of the parameters exceeding state or federal water quality standards (Table 3). However, no tests were completed to determine presence of algal toxins in the groundwater.

Table 3. Range of Value for Water Quality Parameters

Parameter	Measured Values	Units
pH	6.7 – 7.6	
Temperature	38 - 42	F
Specific Conductance	34 – 250	uS/cm
Sodium	3.5 – 22.5	Mg/l
Ammonia	0.0	Mg/l
Potassium	1.5 – 4.2	Mg/l
Magnesium	0.6 – 2.7	Mg/l
Calcium	2.8 – 13.9	Mg/l
Fluoride	0.0 – 0.1	Mg/l
Nitrate	0.0 – 3.2	Mg/l
Phosphate	0.0 – 0.1	Mg/l
Sulfate	0.3 – 38.7	Mg/l

ENVIRONMENTAL EFFECTS

Direct Effects:

Groundwater quality in the shallow aquifer would be slightly degraded under all alternatives through the transfer of algal toxins from the lake into the groundwater during and following algae blooms. This would occur only if the toxins were present in the lake water when the groundwater flow reversal occurs, (lake water recharging groundwater). Under Alternatives 2, 3, and 5 this effect would be expected to decrease after approximately three years; under Alternative 4 some decrease in the effect is expected after seven years; and under Alternatives 1 this effect would continue to occur on annual basis indefinitely. For all alternatives, there is also the potential that groundwater containing algal toxins would migrate and contaminate the water in some of the summer home wells. However, the risk of this potential effect actually occurring is considered to be very low because studies have shown that, due to bank filtration, both cells and dissolved toxins are removed very efficiently. The mean rates of removal for cells were 93.7 – 99.7 per cent and 97.5 – 99.5 per cent for extracellular toxins (Chorus and Bartram, 1999).

Under Alternatives 2, 3, and 5 this risk would be greatly reduced after 3 years because the tui chub population, the primary factor associated with the toxic algae blooms would be eliminated by this time; under Alternative 4, the risk would be reduced after 6 years because the mechanical removal would take at least this long to affect a change in tui chub populations; and under Alternative 1, the risk would be sustained into the future due to lack of action.

Alternatives 1 and 4 would have no other direct effects on the groundwater quality since neither alternative would alter the natural hydrogeological system by lowering the lake level or introducing chemicals to the lake.

Alternatives 2, 3, and 5 would have potential temporary adverse effects to groundwater quality through the addition of rotenone to the surface waters of Diamond Lake. Groundwater may be adversely impacted if chemically treated lake water migrates from the lake into the groundwater. Results of the groundwater studies clearly indicate that the permeability of the shallow aquifer is sufficient to allow chemically treated lake water to recharge the groundwater and potentially migrate at a rate that could impact the overall groundwater quality of the shallow aquifer. Chemically treated lake water would be expected to affect groundwater during the point in the hydrologic cycle where and when the groundwater flow direction shifts from the lake being a groundwater discharge area to a groundwater recharge area (during late summer and fall).

If chemically treated lake water migrated into the groundwater and thus through the hyporheic zone, it would have a direct affect on the fauna living in the hyporheic zone (i.e., zooplankton, bacteria, and other microinvertebrates and macroinvertebrates). It is expected that some of these organisms would be killed by the chemical. The extent of this impact is unknown, however, because the rotenone naturally degrades and dilutes within a relatively short time frame (one to eight weeks), impacts are considered to be temporary. It is expected that fauna associated with the hyporheic zone would recover quickly as water quality returned to normal.

Additionally, if chemically treated lake water migrated into the groundwater, it would have the potential to enter the private wells of the summer cabins along the western shore and temporarily contaminate this water supply. Tolerances for rotenone in potable and irrigation waters have not been established by the U.S. EPA, even though the studies required for setting those tolerances have been completed. This does not mean that rotenone concentrations in drinking waters will create a problem; it just means that U.S. EPA has not established rotenone tolerances at this time. As a result, water containing residues of rotenone cannot be allowed for use as a domestic water source. During the time that rotenone residues are present, alternative water sources must be used for domestic and potable purposes. Depending on the initial rotenone concentration and environmental factors (e.g. temperature), this period can vary from

1 to 8 weeks (CDFG 1994; Finlayson and J. Harrington, unpublished data, presented at Chemical Rehabilitation Projects Symposium, Bozeman, Montana, 1991).

To assess the likelihood that a potential impact to the summer home wells would actually occur, it is necessary to evaluate the mobility of rotenone in the subsurface environment. Dawson et al. (1991) determined that rotenone is not very mobile in sediments. Rotenone leaches vertically less than 2 cm in most soil types, less than 8 cm in sandy soils, and binds readily to most sediments.

Under a worst-case scenario there would be no retardation of the rotenone and it would migrate freely with the groundwater. If this were to occur[6], it would take approximately 11 days to reach a well located 150 feet from the shore. If an attenuation/retardation factor of 10 is applied to the migration, it would take 113 days to reach the same well. Since rotenone shows a strong tendency to adhere to the organic matter in the soil, (Dawson 1991), an attenuation/retardation factor of 10 would be considered conservative, it would more than likely be much greater than 10. CDFG (1994) reported that the California Department of Pesticide Regulation has determined that rotenone is not a potential groundwater contaminant. The authors site multiple studies where well monitoring of groundwater aquifers adjacent and downstream of rotenone applications were conducted. In all cases, analysis of groundwater samples were unable to detect rotenone, rotenolone, or any other organic compounds found in the formulated rotenone product. Thus, the results of these studies in conjunction with the propensity of rotenone to adsorb to sediment and soil and not migrate coincident with groundwater, it is considered unlikely that chemically treated water would enter summer home wells.

This potential contamination would occur in the fall and winter when use of the summer homes is limited. However, in order to minimize any potential risks to homeowner health and safety, groundwater flow patterns would be monitored before and after the rotenone application; if necessary, west shore residents would be advised not to consume the well water; and bottled drinking water would be provided (see mitigation measure in Chapter 2).

Indirect Effects:

Potential effects of algal toxins on groundwater quality described under direct effects above would continue in the long term under some alternatives. For Alternative 1, the risk of degraded groundwater quality and contaminated summer home wells would continue indefinitely. For Alternative 4, these risks would be reduced after seven years but, there is a great degree of uncertainty regarding the potential long-term effectiveness of mechanical tui chub removal at limiting algae blooms (Eilers pers. com). Annual implementation of the contingency plan increases the likelihood of achieving or sustaining water quality improvements over time. For Alternatives 2, 3, and 5, risks to groundwater quality would be reduced after three years and are expected to remain low to none for many years. It is acknowledged under these alternatives that some chub may remain after the rotenone treatment or may be introduced in the future, such that their populations eventually explode again.

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[6] Assumptions are: 1) with groundwater flowing toward the wells of the summer homes; 2) a hydraulic gradient of 0.007 ft/ft; 3) hydraulic conductivity of 2 X 10^{-2} cm/sec (57.6 ft/day); and 4) effective porosity of 0.03 (unitless).

Implementation of the contingency plan is expected to help slow or alleviate future risks if tui chub do reoccur.

There are no additional anticipated long-term indirect effects to groundwater quality associated with Alternatives 2, 3, or 5 because: 1) all potential effects to the groundwater chemistry from the rotenone treatment would be temporary (one to eight weeks); and based on the seepage study chemically treated water in the groundwater would not be expected to surface in Lake Creek or be transported outside the project area. Potential effects of implementing contingency plans for action alternatives are addressed under indirect effects above.

Cumulative Effects:

With the exception of annual algal toxin presence, the existing condition of the groundwater at Diamond Lake is considered to be excellent. Implementation of past, present, and future water rights, as well as the 1954 rotenone treatment (described in the cumulative effects table) are the primary activities that contribute to the cumulative effects of management activities on the groundwater resource at Diamond Lake.

Alternatives 1 and 4 would make no measurable contribution to the cumulative effects on the groundwater in the project area, other than those described under direct and indirect effects. Alternatives 2, 3, and 5 represent a temporary potential modification of groundwater chemistry with no anticipated negative long-term impacts and expected long-term improvements through a reduction in algal toxin presence. Thus, cumulative effects on groundwater are considered to be minor.

Conclusions:

Alternative 1 has potential negative short-term and long-term impacts to groundwater through annual contamination with algal toxins. Alternatives 2, 3, and 5 have potential temporary effects to groundwater from the rotenone treatment with no anticipated long-term negative effects and expected improvements in the long-term through reductions in algal toxins. Alternative 4 has limited short-term effects on groundwater quality because no rotenone treatment would occur. Reductions in algal toxins are expected, but it is uncertain how long the reductions would be sustained through time. Reduction in algal toxins are expected, but there is more uncertainty regarding sustained long-term water quality improvements that for other action alternatives.

GROUNDWATER QUANTITY –GROUNDWATER DISCHARGE AND RECHARGE

AFFECTED ENVIRONMENT

Groundwater interacts with streams and lakes in all types of landscapes in three basic ways: streams and lakes gain water from inflow of groundwater to the streambed or lakebed, they lose water to groundwater by outflow through the streambed or lakebed, or they do both. The natural groundwater flow system around Diamond Lake changes temporally and spatially throughout the yearly hydrologic cycle. During part of the year, the lake is a groundwater discharge area (groundwater moves into the lake) and at other times the lake becomes the recharge area where water from the lake flows into the shallow aquifer immediately surrounding the lake. The timing and length of time in which recharge or discharge to the lake occurs is dependant on the level of water in the lake and of the surrounding groundwater. Any change to the level of the lake will directly affect the discharge and recharge of the shallow aquifer surrounding Diamond Lake, which in turn will affect the water table in the aquifer.

ENVIRONMENTAL EFFECTS

Direct Effects:

Alternatives 1 and 4 would have no direct effect on the groundwater discharge or recharge since neither alternative implements a drawdown that alters the natural hydrogeological system.

Neither Alternatives 2, 3, or 5 would have the potential to produce a temporary adverse affect on groundwater discharge and recharge. These alternatives rely on drawing down the level of the lake approximately 8 feet. By lowering the level of the lake 8 feet, the groundwater would act concomitantly, thus it would continue to discharge into the lake until a new equilibrium level is reached with the new level of the lake. This would effectively lower the groundwater table several feet from the normal groundwater table elevation. Thus, several direct effects would be expected to occur under Alternatives 2, 3, and 5: 1) shallow wells in the summer home area would probably dry up; 2) portions of the wetlands along the southern border of the lake would dewater and become dry; and 3) the water levels in Horse Lake and Teal Lake would lower to the extent that they also could become dry. These potential impacts would be expected to remain until the level of the lake, and thus the groundwater table returns to the pre-drawdown level.

The timeframe over which the groundwater table drops enough to stress the flora and fauna would lag behind the lowering of the lake level by several weeks, perhaps even months. The exact timing would depend on several factors such as, the amount of precipitation that falls over the area during the drawdown period; the amount of recharge to groundwater from snowmelt and precipitation in the high mountain recharge areas; and other factor such as temperature and wind speed.

Potential dewatering of shallow wells (approximately 80 wells) on the west side of the lake would inconvenience some of the residents, particularly if water was unavailable during the high-use summer months. To help reduce inconvenience to potentially affected summer home owners, drinking water would be provided to cabin owners whose wells go dry.

Dewatering the Silent Creek wetlands would not occur at the same rate as lowering the lake. Since the groundwater must flow through a matrix of rock and soil(the aquifer), it would dewater only as fast as water can flow through it, which is dependent on its permeability and the gradient between the lake and groundwater. Additionally, the wetlands would not dewater to complete dryness, due to the effects of capillary action. Capillary action causes a certain amount of water to be retained in the pore spaces, similar to a wet sponge. For example, only a certain amount of water will freely flow out of a completely wet sponge, the remainder is retained in the sponge; this demonstrates the effects of capillary action. Similarly, the wetlands would only dewater to the point where free water would no longer flow. After that the wetlands would gradually become dryer as a result of evaporation[7] and evapotranspiration[8]. When these evaporating processes have acted on the wetlands for some time, flora and fauna would become stressed and the affects of lowering the water table would become evident.

The surface area of wetlands that may be affected also depends on the factors mentioned above (precipitation, temperature, etc.). However, it is expected that most of the southern wetland area (Figure 40) would be temporarily impacted to some degree, the exact extent is impossible to predict with the available data. For analysis purposes, it is assumed that approximately 135 acres of the Silent Creek wetlands would be temporarily impacted. Areas along Silent Creek would experience less of an impact due to the proximity to the local recharge zone of the creek. Affects would be more pronounced the greater the distance from any recharge area.

Monitoring gauges were installed in Horse and Teal Lakes to determine the extent of drying that normally occurs seasonally. Based on data collected from August 28, 2003 through November 5, 2003 it appears that water levels in Horse and Teal Lakes drop naturally in the late summer and fall and may become completely dry periodically in low precipitation years (Figure 7). Under Alternatives 2 and 3, it is considered likely that by late spring or summer following the drawdown, these lakes may have little to no surface water remaining.

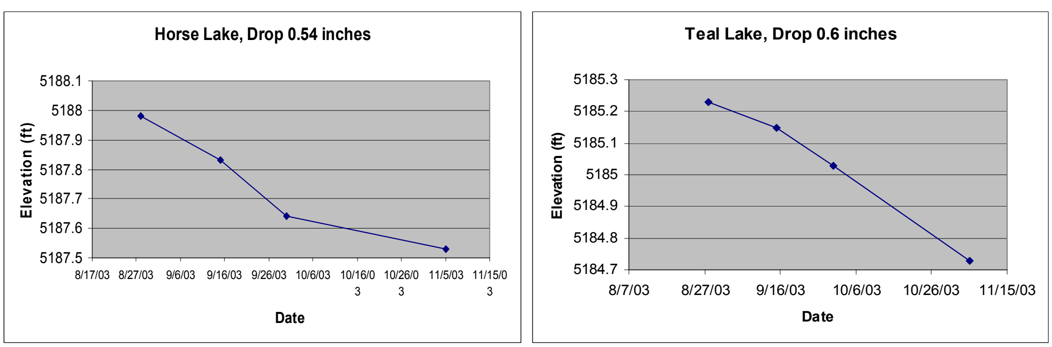

Figure 7. Hydrographs for Teal and Horse Lakes

With the exception of mitigation for one sensitive moss species, there are no recommended measures for mitigating the dewatering of the wetlands or small lakes. However, it should be noted that no long-term deleterious affects to the wetlands are expected because of the temporary lowering of the groundwater table. Most wetland plants can survive short durations of dewatering stress. The groundwater table will rise and return to normal levels as the lake is refilled. Additionally, precipitation during the fall would also help rehydrate exposed plants.

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[7] Evaporation is the process by which liquid water is converted into water vapor.
[8] Evapotranspiration is the combination of evaporation from free water surfaces and transpiration of water from plant surfaces to the atmosphere.

Indirect Effects:

Alternatives 1 and 4 would have no indirect effect on the groundwater discharge or recharge since neither alternative alters the natural hydrogeological system given the lack of any draw downs.

As described above, Alternatives 2, 3, and 5 would not be expected to result in any long-term effects to groundwater, thus they would have no impact on the future groundwater resource. All potential impacts to flora and fauna associated with the temporary dewatering of the Silent Creek wetlands and Horse and Teal Lakes are described in the Wildlife and Botany sections of this chapter.

Cumulative Effects:

Implementation of past, present, and future water rights, as well as the previous lake draw down, (see cumulative effects tables) are the primary activities that contribute to the cumulative effects of management activities on the groundwater resource at Diamond Lake. The existing condition of the groundwater resource is considered to be excellent. Alternatives 2, 3, and 5 represent a temporary, potential modification of the groundwater flow patterns with no anticipated long-term impacts. Based on this information, potential cumulative effects on groundwater associated with these are considered to be minor.

Conclusions:

Alternatives 1 and 4 would have no direct, indirect, or cumulative effects to groundwater levels. Alternatives 2, 3, and 5 have potential temporary effects to groundwater levels with no anticipated long-term negative effects.

Summary:

See Table 4. for the comparison of alternatives effects on groundwater.

Table 4. Comparison of Alternatives Effects on Groundwater.

GROUNDWATER								
Alternatives	Alternative 1 - No Action		Alternative 2 - Rotenone		Alternative 3 - Put and Take Fishery		Alternative 4 - Mechanical & Biological	
Time Period	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term

Indicator **Risk of Well Contamination by Toxins**	No rotenone risks. No meaningful algal toxin risks.	No rotenone risks. No meaningful algal toxin risks.	Rotenone risks low to none with mitigation. No meaningful algal toxin risks.	No rotenone risks. No meaningful algal toxin risks.	Rotenone risks low to none with mitigation. No meaningful algal toxin risks.	No rotenone risks. No meaningful algal toxin risks.	Rotenone risks low to none with mitigation. No meaningful algal toxin risks.	No rotenone risks. No meaningful algal toxin risks.

Alternative 5- Modified Rotenone & Stoking	
Short-term	**Long-term**
Rotenone risks low to none with mitigation. No meaningful algal toxin risks.	No rotenone risks. No meaningful algal toxin risks.

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